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# TESTS OF CHEMICAL MEANS FOR THE CONTROL OF WEEDS

## REPORT OF PROGRESS

BY

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## INTRODUCTION

The cultivation of crops has been actually abandoned on hundreds of acres of some of the most fertile land of the state and the productivity of thousands of acres more is rapidly decreasing through the increase and spread of wild morning-glory and Johnson grass. These weeds have defied practically all control measures so that their appropriation of still more choice land remains unchecked. The mechanical control methods commonly used against these two weeds are hand-digging and clean culture for at least a year. The expense of either of these procedures is always great and sometimes there must be added the loss of the use of the land during the process. The expense involved may equal or exceed the value of the land, but the most serious aspect of the matter is that too often the efficiency of the hand-digging or clean culture operations may fall below a full hundred per cent, in which case the attempt usually results in a complete failure. Any measure short of complete eradication does not, as a rule, justify the expense.

The two plants mentioned are undoubtedly foremost among the weed pests of the state, but all weeds exact a heavy tribute from the tiller of the soil. Other noxious weeds of great economic importance are: the so-called "water-grass" of rice fields, Bermuda grass, wild mustard, wild radish, foxtail, and thistles. These and others have been found very difficult to control and under some conditions their increase and spread has been so rapid as to make the cultivation of the infested fields unprofitable.

Certain of our statutes declare noxious weeds to be a nuisance and empower the county horticultural commissioners to enforce the abatement of such nuisances. The enforcement of these laws, however, is very difficult and in certain sections has not been attempted on account of the magnitude of the undertaking, the expense involved, or the uncertainty of success of the known means commonly used toward eradication.

These conditions constitute a very serious menace to the agriculture of the state and were fully discussed at a meeting of the county horticultural commissioners of California held at Stanford University, July 26, 1915. The use of chemicals was frequently mentioned as a possible solution of the weed problem, but the fact was brought out that very little information is available concerning their usefulness under California conditions. Following this meeting, Mr. William Wood, Los Angeles County Horticultural Commissioner, took up with the director of the agricultural experiment station at Berkeley the matter of an investigation of methods of weed control by means of chemicals. It was suggested that a judicious use of chemicals might solve the problem of the control of those weeds which too often survive and increase in spite of expensive mechanical control measures. The suggested investigation was undertaken by the station in the fall of 1915, and the writer was assigned to the work.

A review of the literature discloses the fact that the use of chemicals has simplified to some extent the solution of the problem of weed control on both agricultural and non-agricultural land in localities other than California.* In one case at least, the use of chemicals for the destruction of weeds has become a common practice.[9] Some of the experiments have demonstrated the usefulness of chemicals for the destruction of weeds on a large scale. Methods which have proved efficient elsewhere may also prove to be efficient here. The soil and climatic conditions of California, however, are so different from those of regions where the chemical method has proved satisfactory, that it is by no means certain that this will be the case. A study of the literature gave encouragement that weed pests might be controlled under local conditions if the conditions were carefully studied and the treatment made accordingly.

Herbicide experiments have been made by several of the railroad companies operating in the state. Probably the first of the county horticultural commissioners to experiment with chemicals for the

* See references on page 97.

control of weeds was Mr. F. W. Waite of El Centro. Other commissioners who have tried this method are Mr. William Wood of Los Angeles, Mr. A. A. Brock of Ventura, and Mr. C. W. Beers of Santa Barbara. Very few data have been published upon the results of these experiments, but the writer has secured much valuable information and confirmatory evidence through correspondence with these experimenters and by occasional inspection of their results. In general, the results were encouraging, but sufficient progress had not been made to establish a definite mode of procedure.

### Investigations by the Insecticide and Fungicide Laboratory

The following progress report describes the more important experiments which have been made during the investigation. A mass of data has been accumulated showing the effect of a number of substances on plant life and on soils, some of which have been sufficiently conclusive to warrant the recommendation of control measures. Some of the experiments have opened up a very promising field for further investigation, while others have been largely negative in character. No attempt is made in this account of the experiments to make definite recommendations for control measures. The practical application of the results is reserved for discussion in separate publications on special topics.*

## ACKNOWLEDGMENTS

An account of the investigations would be incomplete without special mention of the work of two student assistants, Mr. C. C. Barnum and Mr. T. M. Pierce. Their assistance in the planning and execution of the experiments, and in the interpretation of the data, has in no small way contributed to the preparation of this report. Mr. M. R. Miller and Mr. W. C. Matthews have added much of value in photographic records. A number of the county horticultural commissioners, their deputies and inspectors, have freely given advice and both their time and transportation facilities whenever needed. Mr. Fred Lowrie and Mr. George Lowrie have generously allowed the use of land and a pumping plant for experimental purposes.

* Circular 168 of this station, "Spraying for the control of the wild morning-glory within the fog belt," is now available for distribution and may be had upon application to the director.

Mr. F. E. Sullivan, Mr. Geo. T. Scott, and other officials of the Spreckels Sugar Company have shown a hearty spirit of coöperation and have made possible the accumulation of many valuable data by Mr. A. M. Hunt and Mr. H. K. Fox, to whom was assigned the execution of the detail of the coöperative experiments in the Salinas Valley.

### SCOPE OF INVESTIGATIONS

The wild morning-glory is undoubtedly the most difficult to control of any of the weed pests of the state. It is widely distributed and is rapidly spreading. The known methods of control are probably the least satisfactory of those for any weed. The greatest need for investigation appeared to be the control of this pest. The principal part of the problem attacked, therefore, was the control of wild morning-glory upon agricultural land without injury to the soil.

### METHODS OF USING HERBICIDES

Chemicals have been used for the control of weeds in at least two ways in which the manner of action of the poison on the plant is fundamentally different. A well defined conception of this difference in principle is essential to the formulation of control measures. One or the other may be the more suitable procedure to adopt, depending on various conditions. The experiments hereafter reported include tests of these two methods, which, for the purpose of discussion will be referred to as: the "root-absorption method," and the "leaf-absorption method."

## TESTS OF HERBICIDES BY ROOT-ABSORPTION METHOD

Arsenic, sodium cyanide, sulfuric acid, acid sludge, acid tar, salt, carbon bisulfide, copper sulfate, and iron sulfate were tested against wild morning-glory by the root-absorption method. These were applied so that the soil in the vicinity of the roots of the weeds was more or less permeated with the herbicide. In this method the poisons used per square yard varied from one-half an ounce to three and one-half pounds in testing some materials. Experimental plots were located at Whittier, Centerville, and at Spreckels.

## AT WHITTIER AND CENTERVILLE

The first experiments were made at Whittier, September 10, 1915, but conclusions could not be drawn on account of the short duration of the observations. They did indicate, however, that sodium arsenite and sodium cyanide were worthy of a further trial against morning-glory and Johnson grass, and that salt applied at the rate of 3½ pounds per square yard, under the conditions of the experiment, was of no value against the above weeds.

Experiments were made later on the Lowrie Ranch at Centerville, designed principally to test the effect of the root absorption of four materials on morning-glory and the effect of these materials on the soil.

*Experimental Plots.*—The land assigned for the experimental plots was level, and uniformly and heavily infested with wild morning-glory, the vines forming a dense mat, in most places, four or five inches thick. The soil was visible in a few spots only. No other vegetation was growing on the land at the time of the treatment. A crop of garlic had been grown previously on the land and harvested in May or June, 1915.

The land was marked off into rows 1 yard wide and 10 yards long, each row being divided into ten plots of a square yard each. The rows were lettered A, B, C, etc., and the plots of each row numbered 1 to 10, inclusive.

*Chemicals Tested.*—On October 9, 1915, different treatments were made on 93 plots. The four materials tested were:

1. Arsenic in the form of sodium arsenite: a stock solution was prepared by dissolving arsenic trioxide in sodium hydroxide and water in such proportions that each gallon contained the equivalent of 4 pounds of arsenic trioxide.*

2. Sodium cyanide: a stock solution was prepared by dissolving the solid in water and diluting so that each gallon contained 2 pounds of sodium cyanide.

3. Sulfuric acid (commercial 66° Baume): a powerful corrosive to vegetable tissue.

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* The stock solution formula is:

| | |
|---|---|
| White arsenic (arsenic trioxide 99%) | 20 pounds |
| Granulated caustic soda (98%) | 10 pounds |
| Water, to make | 5 gallons |

Detailed directions for the preparation of the above stock solution are given in Circular 168 of this station, Spraying for the control of wild morning-glory within the fog belt.

4. Acid sludge: until recently a waste product in the refining of petroleum distillates with sulfuric acid. Previous unpublished experiments of Mr. E. R. de Ong and the writer to study the action of petroleum oils on citrus and other foliage had indicated that the constituents of petroleum distillates which are capable of being removed by refining with sulfuric acid are much more toxic to foliage than other constituents. It was thought that acid sludge, therefore, containing these highly toxic constituents of petroleum as well as an excess of sulfuric acid, might prove to be an efficient and economical herbicide.

*Manner of Application.*—For each treatment a quantity of the stock solution or liquid was measured out and diluted to a volume of either one or two gallons. All of the diluted solution was then uniformly distributed over one of the square-yard plots by means of an ordinary garden sprinkling pot. It was found by preliminary trial that a gallon of water applied to a square-yard area of the soil would thoroughly soak the ground for about an inch below the surface. This quantity was therefore applied to some of the plots; on others the amount of liquid was doubled in order to ascertain whether or not the greater amount of liquid would result in permeating the soil with the poisons to a greater depth than the smaller amounts. It was thought that the vines might affect the absorption of the poisons, so the vines were removed from some of the plots before applying the solutions.

Table 1 illustrates in detail the treatment given the individual plots.

## AT SPRECKELS

Coöperative experiments with the Spreckels Sugar Company were started in March, 1916, on its ranches in the Salinas Valley.

The materials tested on morning-glory were: iron sulfate, copper sulfate, acid sludge,* acid tar* (derived from acid sludge), sulfuric acid, carbon bisulfide, and "Nonpariel" (a commercial herbicide, consisting principally of carbon bisulfide).

Application of the materials was made on square-yard plots in the same manner as in the Centerville experiments with the exception of the carbon bisulfide and Nonpariel. These were applied by making holes on the plots at intervals with an iron rod and pouring into the holes a quantity of the material and immediately filling the holes with earth.

*Furnished by courtesy of the Union Oil Company of California.

TABLE 1

TREATMENTS ON 93 SQUARE-YARD PLOTS AT CENTERVILLE, OCTOBER 9, 1915.

The large figures indicate the amount in ounces of the material applied to each plot, solids expressed in ounces avoirdupois, and liquids in fluid ounces

| Material applied | Row | Plot numbers 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Treatment of row |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arsenic trioxide | A | 16 | 12 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 gallons solution; vines on. |
| Arsenic trioxide | B | 16 | 12 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 gallons solution; vines removed. |
| Arsenic trioxide | C | 8 | 6 | 4 | 3½ | 3 | 2½ | 2 | 1½ | 1 | ½ | 1 gallon solution; vines on. |
| Arsenic trioxide | D | 8 | 6 | 4 | 3½ | 3 | 2½ | 2 | 1½ | 1 | ½ | 1 gallon solution; vines removed. |
| | E | | | | Check | | | | | | | None. |
| Sodium cyanide | F | 16 | 12 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 gallons solution; vines on. |
| Sodium cyanide | G | 16 | 12 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 gallons solution; vines removed. |
| Sodium cyanide | H | 8 | 6 | 4 | 3½ | 3 | 2½ | 2 | 1½ | 1 | ½ | 1 gallon solution; vines on. |
| Sodium cyanide | I | 8 | 6 | 4 | 3½ | 3 | 2½ | 2 | 1½ | 1 | ½ | 1 gallon solution; vines removed. |
| | J | | | | Check | | | | | | | None. |
| Sulfuric acid | K | 24 | 20 | 16 | 12 | 8 | 4 | .... | .... | .... | .... | 1 gallon solution; vines on. |
| Acid sludge | L | 20 | 16 | 12 | 8 | 4 | 2 | .... | .... | 8* | .... | 1 gallon solution; vines on. |

* Two gallons of solution applied.

## Conclusions Concerning Root-Absorption Method

Inasmuch as the root-absorption method gave little promise of offering a solution of the morning-glory problem, space will not be taken for a detailed report of the results. Table 2 will be of interest in showing the cost of the more effective materials tested. Costs shown in this table and elsewhere in this report are calculated from the retail prices prevailing at the time of the treatments.* The cost of solids (arsenic trioxide and sodium cyanide) is given in ounces avoidupois; the cost of liquids (sulfuric acid and carbon bisulfide) is given in fluid ounces, using the figure 1.8 as the specific gravity of commercial sulfuric acid, and 1.27 as that of carbon bisulfide.

TABLE 2

Cost of More Effective Materials Tested by Root-Absorption Method

| | Arsenic trioxide | Sodium cyanide | Sulfuric acid | Carbon bisulfide |
|---|---|---|---|---|
| Cost per ounce as applied, approximate | $0.008 | $0.020 | $0.0025 | $0.006 |
| Least amount per square yard giving any promise of control of morning-glory, ounces | 3 | 3 | 20 | 10 |
| Cost per square yard | $0.024 | $0.06 | $0.05 | $0.06 |
| Cost per acre | 117.90 | 290.40 | 242.00 | 305.50 |
| Least amount per square yard preventing the growth of practically all vegetation except morning-glory for 14 months on undisturbed soil, ounces | 1 | 12 | 24 | Soil not injured by this material |
| Cost per square yard | $0.008 | $0.24 | $0.06 | ..... |
| Cost per acre | 39.30 | 1,160.60 | 290.40 | ..... |

Cost of the materials in table 2 are calculated from the following prices: Arsenic trioxide, @ 8c per lb.; sodium cyanide, @ 32c per lb.; carbon bisulfide, @90c per gal.; caustic soda, @ 10c per lb.; sulfuric acid, @ 2c per lb.

No data are available on the cost of acid sludge and acid tar. Until their recent use in the flotation process for the concentration of certain low grade ores, they were both waste products in refining petroleum distillates and had very little commercial value.

Nonpariel sells at about the same rate as carbon bisulfide or cheaper.

No sweeping conclusions are justified from the results of the experiments. Whether or not the results would be duplicated on other soils, or under different climatic conditions, or if the chemical were applied at other seasons of the year as yet can not be predicated.

* These prices are above normal. Since the preparation of the manuscript, the price of arsenic has advanced to 23 cents per pound. Other materials are also higher and some are difficult to obtain at any price. The present unsettled condition of the market does not warrant a revision of prices.

## CONTROL OF WILD MORNING-GLORY

None of the root-absorption experiments seemed to point the way for the control of wild morning-glory on agricultural land at a reasonable expense and without serious injury to the soil. In the experiments, and in all cases that have come to the attention of the writer, where a chemical has been used by this method, the cost would prohibit its use as a *control* measure, except on small areas; if *eradication* has not been accomplished, the results have not justified the means. Furthermore, it was found that in using a non-volatile herbicide (such as salt, arsenic, sodium cyanide, sulfuric acid, etc.), if the soil is sufficiently

Fig. 1.—The effect of arsenic on the soil when applied by the root-absorption method (see table 1).

"Incidental to the main object of the experiments, . . . data . . . show the superiority of arsenic as a soil sterilizer."

permeated with the chemical to destroy the roots of the wild morning-glory, it is rendered unfit for the growing of crops for many months.* Carbon bisulfide, on the other hand, is a volatile herbicide and appears to produce no injurious effects on the soil. It is also quite effective against morning-glory, but the expense of application and the cost of material are both high.

## SOIL STERILIZATION

Incidental to the main object of the experiments, the control of wild morning-glory on agricultural land, data have been obtained which show the superiority of arsenic as a soil sterilizer (compare figures 1, 2, and 3). While arsenic has apparently failed to actually eradicate

* See further discussions of the effects of arsenic on the soil on pages 90–91.

the wild morning-glory, using as high as a pound to the square yard, it can be used as a soil sterilizer in respect to a great variety of weeds. All of the Centerville plots to which an ounce or more of arsenic trioxide had been applied per square yard were barren of all vegetation, except morning-glory, for fourteen months (fig. 1), notwithstanding the leaching by the rains of two winters. The minimum cost of materials for the production of this result was less than one cent per square yard or about forty dollars per acre.* This would not be prohibitive for the prevention of weed growth on gravelled walks, tennis courts,

Fig. 2.—The effect of sodium cyanide on the soil when applied by the root-absorption method (see table 1).

On all plots receiving six ounces or less of sodium cyanide the final growth of miscellaneous weeds was fully equal to that on the checks. The smaller amounts appeared to stimulate the growth.

roadways, fencerows, or in other places where soil sterilization is desired.

One significant fact in connection with soil sterilization is that any amount of arsenic in excess of one ounce per square yard appears to have been a waste of material unless future observations will show that larger amounts will have a more lasting effect.

The experiments have furnished a basis for further experiments in the problem of weed control on railroad right-of-ways. This matter has already received considerable attention by a number of railroads, but the danger of poisoning live stock has had a restraining influence

* See footnote on page 74.

on the use of arsenic for weed control in this connection. The suggestion to add some substance to the herbicide as a repellant to stock has been given attention, but sufficient progress has not yet been made to warrant publication.

## TESTS OF HERBICIDES BY LEAF-ABSORPTION METHOD

The preceding experiments are in sharp contrast to those reported below. In the former, an attempt was made to poison the soil in the

Fig. 3.—The effect of sulfuric acid on the soil when applied by the root-absorption method (see table 1).

vicinity of the root system; in the latter, the poisons were not applied to the soil, but were sprayed on the foliage of the weeds. For the purpose of discussion, the latter method will be referred to as the "leaf-absorption method." The amount of poison required in this method is very small so that even though a very poisonous substance is used, the quantity will be so evently distributed over the area treated that the probability of injury to the soil is reduced to the minimum. It has been demonstrated that wild mustard, wild radish, and other annual weeds can be economically controlled in the grain fields of the middle west by spraying with a solution of iron sulfate or of copper sulfate.[1, 2] A dilute spray of sodium arsenite is extensively employed in the Hawaiian Islands for the control of weeds on sugar, rubber, and

pineapple plantations.[4, 9, 10] Experiments have shown that certain oil sprays are effective for the control of wild onion and wild garlic in Indiana and Ohio.[7, 11] Experiments in Australia have proved the effectiveness of an arsenical spray for the destruction of cacti.[5] In the literature just cited, the leaf-absorption method has been demonstrated to be effective for the control of weeds on a large scale. So far as known, however, this method has not been tried against the wild morning-glory, a persistent and deep-rooted perennial (figs. 4 and 5). Bioletti[3] reports finding roots of this weed well supplied with starch

Fig. 4.—A remarkably heavy infestation of wild morning-glory covering about two acres in the center of a beet field.

The stand of vines was well above one's knees.

and capable of producing new shoots at a depth of fourteen feet, the smallest piece of which is capable of growing and originating a new plant.

## PRELIMINARY EXPERIMENT AT CENTERVILLE

Following the tests of the root-absorption method at Centerville, a test was made at the same place of the leaf-absorption method so much in use in Hawaii.[9]

*Experimental Plot.*—The plot selected for the experiment was immediately adjoining the plots used for the root-absorption experiments, and consisted of 51½ square yards, quite uniformly and heavily infested with morning-glory, the vines forming a dense mat four or five inches thick in most places. No other vegetation was growing on the plot at the time of treatment. A crop of garlic had been grown on the land and harvested in May or June, 1915. The plot was designated as Spray Plot 1.

*Chemical Tested.*—A dilute arsenical solution was prepared by mixing 4 fluid ounces of the arsenic stock solution (p. 71) with 3 gallons of water. This made a solution roughly equivalent to a dilution of the stock solution 1:100, or 4 pounds of arsenic trioxide per 100 gallons. The three gallons contained the equivalent of 2 ounces of arsenic trioxide.

Fig. 5.—Vines and root of wild morning-glory.

*Manner of Application.*—The solution was applied November 5, 1915, to the morning-glory vines on the plot by means of a bucket spray pump. Just enough of the spray was used to moisten the leaves and stems of the vines only, no attention being given to the few bare spots where the soil was visible. The 3 gallons of solution was found sufficient for the purpose, the whole plot of 51½ square yards thus receiving only 2 ounces of arsenic trioxide.

*Results.*—One week after the application of the spray the morning-glory vines were found completely killed to the ground, but the roots appeared to be normal. A similar observation was made a week later. Three weeks after spraying, however, the effects observed on the roots of the morning-glory vines were remarkable. The usual new growth of sprouts from the roots after the destruction of the vines had not occurred. The roots were moldy and disintegrating to a depth of several feet below the surface. Forty-five days after spraying, only nine plants had produced any new growth above ground on the whole plot, while it was estimated that fully six hundred plants were above the surface on an equal area of the adjoining field which had been recently gone over with the weed knife. The usual winter growth of wild grasses and other weeds was well started in the vicinity, the growth of which on the sprayed plot was fully equal to that on the adjoining plot.

*Comments.*—This experiment indicated that the leaf-absorption method for the control of morning-glory on agricultural land has great possibilities. The cost of materials did not exceed $1.50 per acre,* the poison having been applied at the rate of 12 pounds per acre; the remedy was applied as a spray, which is probably the most economical manner of application; the apparent control of the weed at a comparatively trifling expense was almost equal to the best results obtained in any of the root-absorption method experiments; and no ill effects to the soil were observed. The possible utility of this method was also noted for the control of miscellaneous weeds upon non-agricultural land where cultivation is difficult or impossible.

In view of the results obtained in the first test of the leaf-absorption experiment it seemed desirable to make as thorough a study as possible of this method and to secure sufficient land for the purpose with reasonable assurance that the experiments would not be molested.

## PRELIMINARY EXPERIMENTS AT DAVIS

A series of experiments at the University Farm at Davis was outlined and work started before the occurrence of the winter frosts of 1915.

*Experimental Plots.*—Most of the land assigned for the experiments was well infested with morning-glory. It had been used in the summer of 1915 for a crop of vegetables. No plants other than morning-glory were growing on the plots when the experiments were begun.

The land to be used for our tests was divided into thirty plots

* See footnote on page 74.

of one-fortieth of an acre each. The experiments were outlined, principally, to determine the most suitable of three forms of soluble arsenic and the time of the year to obtain the best absorption of these materials through the aerial parts of the weeds.

*Chemicals Tested and Manner of Application.*—On December 23, 1915, one of the plots was treated in exactly the same manner as described in the preliminary experiments at Centerville. A dilute arsenical solution was prepared by mixing 9⅓ fluid ounces of the arsenic stock solution described on page 71 with 7 gallons of water. Another plot was sprayed the same day with a solution of the same concentration of arsenic but made up with half the quantity of caustic soda. A third was sprayed the following day with a solution of *arsenic acid* containing the same amount of actual arsenic as the two previously described sprays.

*Results Complicated the Problem.*—Repeated observations subsequent to the application of these sprays at Davis failed to disclose any injury to the roots of the morning-glory vines on any of the plots. The striking results of the Centerville experiment and the failure of similar treatments two months later at Davis clearly suggested the importance of making a study of all conditions which might affect the results. It was thought that the climate, the season of the year, the weather at or near the time of application, the condition of the plants, the type and condition of the soil, individually or collectively, and possibly others, might be factors influencing the results to a greater or less extent.

## PLAN OF EXPERIMENTS IN 1916

The problem at once became so complicated that it seemed wise to limit the future experiments to a study of the leaf-absorption method, and to pay most attention to making a thorough test of the arsenical spray treatment under as many conditions as possible. The winter rains and the killing of the morning-glory vines by the frost prevented any further experiments until March, 1916, at which time new ones were started.

Comprehensive series of experiments were carried on during the growing season of 1916 and until the vines were killed by the frosts. The killing frosts of 1916 occurred earlier than those of 1915 so that the experiments had to be discontinued at an earlier date. The Centerville and Davis experiments were continued and coöperative experiments in the Salinas Valley in coöperation with the Spreckels Sugar

Company were also started, as well as a series of experiments at Berkeley.

Experimental plots were thus located on different types of soil in different localities, upon soil of the same type but differing in drainage conditions, and upon both lightly and heavily infested plots. The weather conditions at the various experimental plots were different. The climate at Davis is semiarid, while the remainder of the plots were within the fog belt, although differing somewhat in distance from the coast. The details of all the experiments of 1916 will not be described in full in this progress report but only such observations as seem to be the most significant.

## FURTHER EXPERIMENTS AT CENTERVILLE

The experiments at Centerville were continued on more infested land adjoining the plots previously used.

*Outline of Experiments and Subdivision of Plots.*—In order to make observations on the results to be obtained by repeated sprayings at different intervals, Spray Plot 1 was divided into two parts, A and B. Spray Plot 1A was further divided into five small plots ( 1 by 5 yards) which were lettered a, b, c, d, and e; certain ones to be resprayed at irregular intervals, depending upon the growth of weeds.

Spray Plot 1B to be resprayed once in the fall of 1916.

Convenient sized plots (2 by 10 yards) were staked out adjoining Spray Plot 1, to be sprayed at different times of the year.

The manner of subdivision and the dates on which the sprays were applied are indicated in tables 3 and 4.

TABLE 3

SPRAY PLOTS 1A AND 1B, SHOWING DATES OF SPRAYING

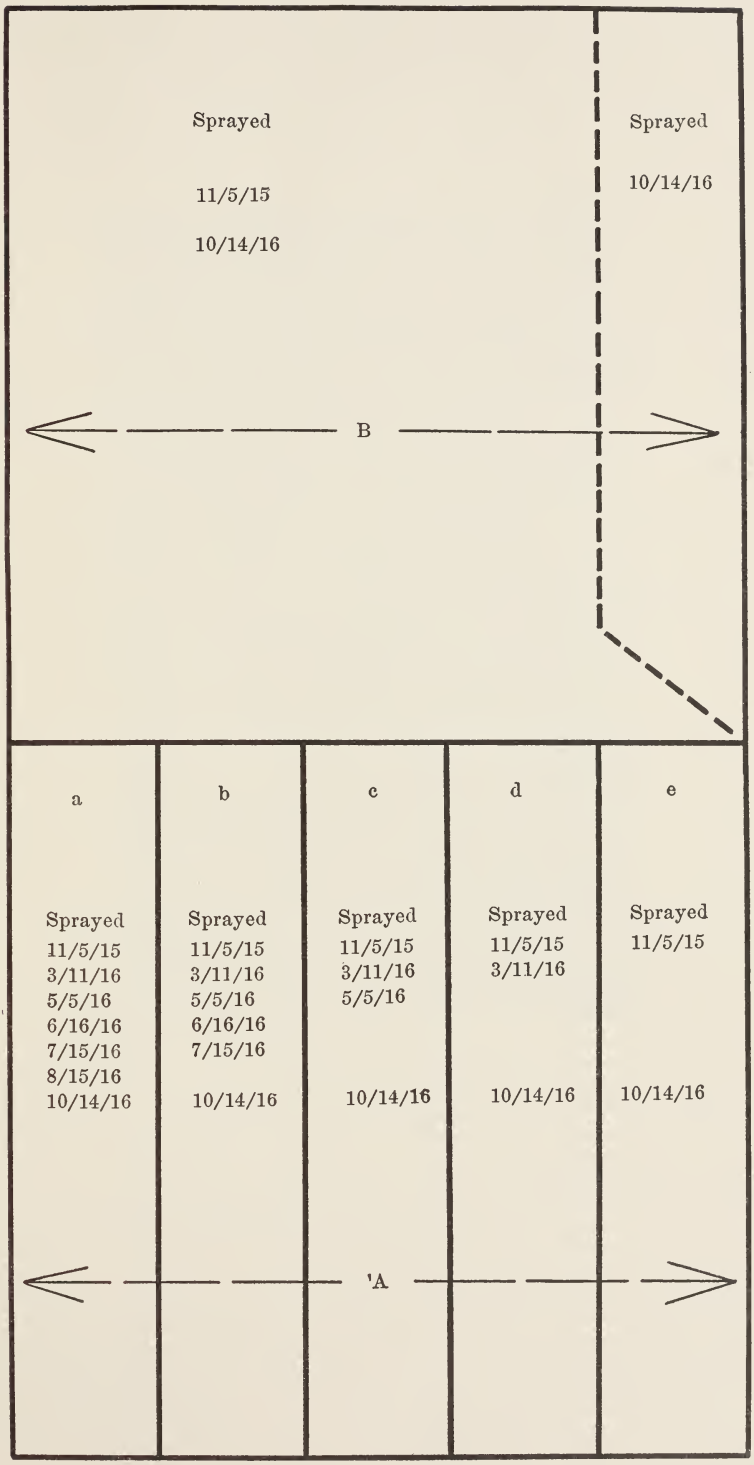

TABLE 4

SPRAY PLOTS 2 to 7

SOUTH OF AND ADJOINING SPRAY PLOT 1. PLOTS 2 BY 10 YARDS CHECKS 1 BY 10 YARDS. SHOWING DATES OF SPRAYINGS

| | | | |
|---|---|---|---|
| R | CHECK | Sprayed 10/14/16 | |
| S<br>T | **Spray Plot 2** | Sprayed 3/11/16 and 10/14/16 | |
| U<br>V | **Spray Plot 3** | Sprayed 6/16/16 and 10/14/16 | Garlic field in 1915 |
| W | CHECK | Sprayed 10/14/16 | |
| X<br>Y | **Spray Plot 4** | Sprayed 7/15/16 and 10/14/16 | |
| Z | **Spray Plot 5** | Sprayed 8/15/16 and 10/14/16 | Tomato field in 1916 |
| | CHECK | Sprayed 10/14/16 | |
| | **Spray Plot 6** | Sprayed 9/16/16 and 11/11/16 | |
| | **Spray Plot 7** | Sprayed 10/14/16 | |
| | CHECK | Sprayed 11/11/16 | |

*Chemicals Tested and Manner of Application.*—The sprays were all made up and applied in the manner described in the preliminary experiment at Centerville. Four fluid ounces of the arsenic stock solution (p. 71) were mixed with 3 gallons of water. The solutions were applied by means of a pressure sprayer, using just enough to moisten the foliage of the weeds. The quantity required for the purpose was

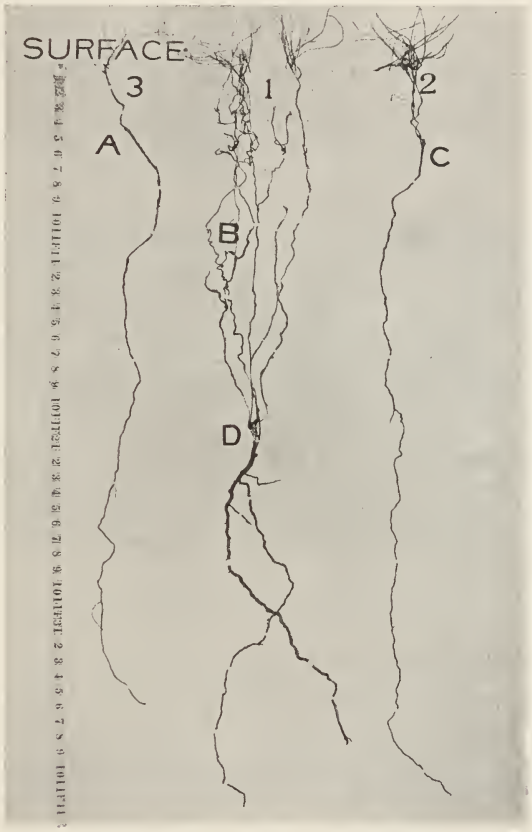


Fig. 6.—Typical root systems of morning-glory plants at Centerville, destroyed by an arsenical spray applied to the aerial parts only.

Spray applied September 16, 1916; roots dug, October 14, 1916. Root 1 was dissected out to a distance of 4 feet, 2 inches below the surface and was one-half inch in diameter at D.

roughly equivalent to 300 gallons per acre, containing sodium arsenite equivalent to 12 pounds of arsenic trioxide, and 6 pounds of sodium hydroxide. The cost of materials for the 300 gallons of spray was estimated to be $1.50 at retail price prevailing at the time of treatment.*

* See footnote on page 74.

*Results.*—Each spraying entirely killed the vines of the morning-glory to the surface of the ground, as well as most of the broad-leafed plants. The grasses were much less affected. The roots of the morning-glory were not materially injured by any spray applied between March and August, 1916, but the spray applied August 15, 1916, caused marked injury to the roots of the morning-glory. The usual growth of new sprouts was markedly less than usual, only 18 having reached the surface within one month after spraying. Even these seemed to be lacking in vitality. Many roots were apparently dead from 1½ to 2 feet below the surface of the ground.

The effect of the spray applied September 16, 1916, was still more encouraging. One month after the application of the spray, a hole

Fig. 7.—Showing the injured condition of the interior of a section of the lower end of root 1, figure 6, four feet below the surface.

was dug on the plot to a depth of five feet. Working laterally from this hole, largely by means of trowel and geology pick, the soil was removed from some twenty-five roots (see fig. 6). Only one of these roots appeared to be normal. The rest were shrivelled, moldy, and disintegrated from the base of the vine stems to two or three feet below the surface, the remainder still being plump. On exposing the interior of these plump lower sections of the roots, the cambium was found to be turned to a chocolate brown color and a very pronounced "sour" odor was given off. Figure 7 will give an idea of the appearance of the interior of a section taken from the lower end of root 1, figure 6, four feet below the surface.

*October Sprayings Most Effective.*—All plots previously sprayed (with the exception of Spray Plot 6) were sprayed again October 14, 1916, and the check plots between were also sprayed in order to make observations on the efficiency of two sprayings at different intervals

and to make the attempt to disinfest all the experimental plots. The October spraying appeared to be more effective than any previous one.

On November 11, 1916, a count was made of the morning-glory plants producing new vines on the various plots and their condition was noted with the results shown in table 5.

TABLE 5

OBSERVATIONS ON CENTERVILLE PLOTS

| Spray plot No. | When sprayed | Observations, Nov. 11, 1916: Number of vines | Condition of vines |
|---|---|---|---|
| 1 | Plot 1B Nov., 1915, Oct., 1916 | 27 | Sickly |
| | Plot 1A (see map, p. 83). | | |
| Check | October, 1916 | 0 | |
| 2 | March and October, 1916 | 8 | Sickly |
| 3 | June and October, 1916 | 10 | Sickly |
| Check | October, 1916 | 3 | Sickly |
| 4 | July and October, 1916 | 5 | Sickly |
| 5 | August and October, 1916 | 40 | Vigorous |
| Check | October, 1916 | 0 | |
| 6 | September only, 1916 | 34 | Sickly |
| 7 | October only, 1916 | 5 | Sickly |
| | TOTAL | 132 | |

Total area included in the above count ..... 200 sq.yds.
Estimated number of plants on this area before treatment ..... 2,400
Total number of plants producing new vines on this area after treatment ..... 132
Numbered plots, 2 by 10 yards; checks, 1 by 10 yards.

## RÉSUMÉ OF LEAF-ABSORPTION EXPERIMENTS

The experiments at Davis were continued during 1916 until the vines were killed by the frost early in November. The three arsenical sprays (p. 81) were applied to additional plots in the months of March, May, June, July, August, September, and October. None of the sprayings produced very satisfactory results. A comparison of the efficiency of the three forms of arsenic is, therefore, impossible. In some of the experiments the arsenic acid spray seemed to be more severe in its action than others.

The Spreckles Sugar Company has provided for the full time of one man since March, 1916, for coöperative experiments on their ranches in the Salinas Valley. Arsenical sprays of different concentrations were applied to morning-glory every month of the year from March to December. The problem of the control of miscellaneous weeds

along their extensive irrigation system and along roadways was also attacked. Arsenic was given the most extensive trial, and, in addition, sodium cyanide, iron sulfate, copper sulfate, acid sludge, and acid tar were tested.

A number of experiments were also made at Berkeley, testing the arsenical spray on morning-glory.

Each set of experiments has contributed materially in throwing light on the problem of the control of weeds by means of chemicals. The results of the above experiments are summarized under the various headings below.

## PETROLEUM PRODUCTS AS HERBICIDES

While arsenic was found to be not only the most potent of the plant poisons thus far tested, but also the cheapest, there are certain dangers attending its use which must not be overlooked. This fact has led the writer to make a search for an herbicide which is less poisonous to man and animals, and yet not prohibitive in price. The experiments in this direction were rather limited but were sufficiently encouraging to warrant further investigation.

A spray composed of equal parts of acid sludge (p. 72) and water, applied to wild morning-glory vines in October, 1916, appeared to be as effective as arsenic in destroying the weed. Acid tar( a derivative of acid sludge containing less free acid) gave encouraging results on morning-glory.

The above materials applied as a spray, either pure or diluted, were especially effective on grasses. A spray of acid tar applied to a plot of succulent grass (principally foxtail and wild oats) caused withering and browning of the leaves within half an hour after application; within twenty-four hours the grass readily took fire from a lighted match and burned.

Petroleum-distillate sprays were tested on miscellaneous weeds. The results indicated that certain of these distillates were more effective in destroying grasses than sodium arsenite, while sodium arsenite was generally more effective on the broad-leafed plants than the distillates. The cheaper grades of distillates were more effective than refined distillates such as kerosene and similar products. Petroleum products containing a large percentage of aromatic and "cracked" oils were more effective than those containing a lesser percentage.

## ARSENIC ON MISCELLANEOUS ANNUAL WEEDS

The growth of many annual weeds was easily killed to the ground by spraying with a dilute arsenical spray. The roots were not always destroyed and would often produce a new growth.

Annual weeds of more tender foliage were destroyed with a spray containing the equivalent of four pounds of arsenic trioxide per hundred gallons. The grasses were more resistant to arsenic than most other weeds. These and weeds of more hardy foliage seemed to require a more concentrated spray than the above. Sprays containing the equivalent of eight to twenty pounds of arsenic trioxide per hundred gallons have usually given satisfactory results in the control of the more resistant annual weeds. The optimum concentration was not determined, but it appears that it will have to be varied according to the nature of the weeds.

Fig. 8.—The effect of arsenic on the soil when applied by the leaf absorption method (see table 3).

Spray Plot 1A had been sprayed twice, November 5, 1915, and March 11, 1916; and Spray Plot 1B had been sprayed once, November 5, 1915, when the photo was taken, April 28, 1916. The growth of miscellaneous weeds on the plots after treatment has been used throughout the experiments as an indication of the effect of the treatments on the soil.

The arsenical-spray method has been shown to be suitable for the control of miscellaneous annual weeds growing along irrigation ditches, fencerows, and other places where cultivation is difficult or impossible and for the prevention of the maturing of seeds of perennial noxious weeds on uncultivated land.

*Soap as a Spreader.*—The addition of three or four pounds of soap (first dissolved in hot water) to each hundred gallons greatly increased the effectiveness of the arsenical sprays. This addition was found to be especially desirable when the sprays were used against the grasses or other waxy-coated foliage upon which the spray had a tendency to collect in drops.

### ARSENIC ON WILD MORNING-GLORY

*Effect on the Soil.*—The germination and growth of the natural weed seeds on the plots after treatment has been used throughout

Fig. 9.—The effect of arsenic on the soil when applied by the leaf absorption method (see table 3).

A closer view of Spray Plot 1B. The luxuriant growth of weeds subsequent to spraying is good evidence of the non-injurious effect of arsenic on the soil when applied by the leaf absorption method.

the experiments as an indication of the effect of the treatments on the soil. The luxuriant growth of weeds shown in figures 8 and 9 is good evidence of the non-injurious effect of arsenic on the soil when applied by the leaf-absorption method. While arsenic has been shown to be very toxic to the soil when applied in large quantities, as in the root-absorption method, the amount required by the leaf-absorption method is so small that no ill effects to the soil could be detected. Even six successive applications of the spray failed to reveal any indication of deleterious effects.

A study of the effect of arsenic on the soil organisms that produce nitric nitrogen has been made by Professor W. F. Gericke, of the Division of Soil Chemistry and Bacteriology of this station. So far as this important function of soil fertility is concerned, this study has shown that an amount of arsenic equivalent to one hundred successive applications of the spray, as applied to the Centerville plots, produced no toxic effect on the nitrifying bacteria. It is evident, however, that the functions of the soil are interfered with when large quantities of arsenic are applied. In the root-absorption experiments, the above amount of arsenic rendered the soil barren of all vegetation, except morning-glory, for many months.

The writer is indebted to Professor Gericke for the following contribution concerning the effect of arsenic on the flora of the soil:

TABLE 6

NITRIFICATION OF SOIL FROM CENTERVILLE

Treated with sodium arsenite to kill weeds

| Laboratory number | Plot number* | Depth of sample in inches | $As_2O_3$ applied to plots in the form of sodium arsenite oz. per sq. yd. | Mg. of nitric nitrogen per 100 gms. soil. Duplicates (1) | (2) | Average of determinations |
|---|---|---|---|---|---|---|
| 1 | A–1 | 0–6 | 16 | 2.3 | 4.0 | 3.16 |
| 2 | A–1 | 12–24 | 16 | 20.0 | 14.0 | 17.00 |
| 3 | A–3 | 0–6 | 8 | 18.0 | 18.0 | 18.00 |
| 4 | A–3 | 12–24 | 8 | 10.4 | 12.0 | 11.20 |
| 5 | A–7 | 0–6 | 4 | 24.8 | 24.0 | 24.40 |
| 6 | A–7 | 12–24 | 4 | 26.0 | 26.8 | 26.40 |
| 7 | A–10 | 0–6 | 1 | 24.8 | 26.0 | 25.40 |
| 8 | A–10 | 12–24 | 1 | 24 0 | 20.0 | 22.00 |
| 9 | E–2 | 0–6 | 0 | 20.0 | 20.0 | 20.00 |
| 10 | E–2 | 12–24 | 0 | 22.0 | 20.0 | 21.00 |

* See table 1, page 73.

The data in table 6 show that the sodium arsenite applied at the rate of the equivalent of 8 ounces, or more, of arsenic trioxide per square yard was toxic to the soil organism that produced nitrification. Toxic effects were noted in both surface and subsoil in these larger applications. On the plots in which the sodium-arsenite application was equivalent to 4 ounces or less of arsenic trioxide per square yard, no toxic effect was noted; on the contrary, the results indicate stimulation of the soil organism that produce nitric nitrogen. The results are in accord with the data published by Greaves[6] who reported stimulating effects to ammonification and nitrification in soil to which small amounts of certain arsenic compounds were added.

*Concentration of Spray.*—Different concentrations of arsenical sprays were tried at Spreckels, varying from the equivalent of four ounces to sixteen pounds of arsenic trioxide per hundred gallons. The concentration of arsenic used throughout the Centerville experi-

ments (four pounds of arsenic trioxide per hundred gallons) appeared to be as effective for the control of morning-glory as any other tested. Much lower concentrations were ineffective. Higher concentrations appeared to produce no better results and possibly not as good. The stronger sprays in some instances appeared to collapse the tissues of the vines and stop the circulation of the sap before the poison had its full effect upon the roots.

*Repeated Applications of Small Doses.*—Repeated small doses of arsenic were sprayed upon morning-glory vines at intervals of one day, four days, and longer, depending upon the growth of the new vines. These experiments were tried in the spring of 1916 to ascertain if the effects of arsenic applied in small doses would be cumulative. None of these treatments, however, appeared to injure the roots in any way, although the experiments were continued well into the summer months.

*Absorbing Surface.*—The observation has been made many times that the roots of morning-glory plants without a good vine development (that is, with only a small absorbing surface) were not severely injured by the application of a poisonous spray to the vines; and that parts of the plants beneath the surface at the time of spraying would make a normal growth of vines subsequently, if not connected with a part which did have a good growth of vines. This observation contributes important evidence not only of the absorption of poisons through the aerial parts of wild morning-glory, but also of the non-injurious effect of the arsenical spray on the soil.

The broad-leafed weeds were generally more affected by arsenical sprays than the grasses. The effect of arsenic upon foliage (especially on grasses and other waxy-coated foliage) was more severe if soap was added to the spray to act as a spreader.

*The Time of the Year.*—The arsenical sprays, excepting a few very dilute ones, completely killed the vines of the wild morning-glory at whatever time of the year they were applied.

The earliest time at which any of these sprays were at all injurious to the roots was in May, at Davis, where the weed matured earlier than on any of the other experimental plots. At this time many of the plants were in the green seed-pod stage. All sprayings at Davis from May to October produced at least slight injury to the roots, apparently depending on weather condition, but none of them was considered a satisfactory control.

The spring and early summer sprayings on all of the other experi-

mental plots produced little or no injury to the roots of the weed, while the late summer and fall sprayings produced marked injury to the roots of mature vines. The amount of injury apparently increased as the season advanced. The most satisfactory results in 1915 were obtained in November; in 1916, in October.

The establishment of this point, however, was not a solution of the problem, as will be shown by later discussion.

*Maturity of Plants.*—Observations which appear to have an important bearing on the problem are as follows:

Fig. 10.—The maturity of the plant influences the results.

The roots of some of the morning-glory plants at Centerville were slightly injured by an arsenical spray applied June, 1916, and by one applied a month later. The roots of those plants which were in seed or late blossom at the time of spraying appeared to have been most severely injured. The same observation has been made repeatedly during the progress of the other experiments.

A spray was applied to mature morning-glory plants at Berkeley in September. The roots of these plants were completely destroyed by the spray. A spray applied to another plot, however, under practically the same conditions, failed to injure the roots. It was observed that in the latter case the vines were actively growing at the time of treatment, since they had been cut about four weeks previously with a weed knife. One plant, however, was found the roots of which were

moldy and disintegrated as far as dissected out. This vine apparently had been missed by the weed knife and was much older than the other vines. It had a number of green seed-pods attached, while the other vines had not yet blossomed. The two disintegrated roots shown at the left of figure 10 were taken from the plant mentioned above as being in seed at the time of spraying; the two uninjured roots at the right of the figure from which normal new sprouts had originated were taken from another plant only eight inches from the first. So far

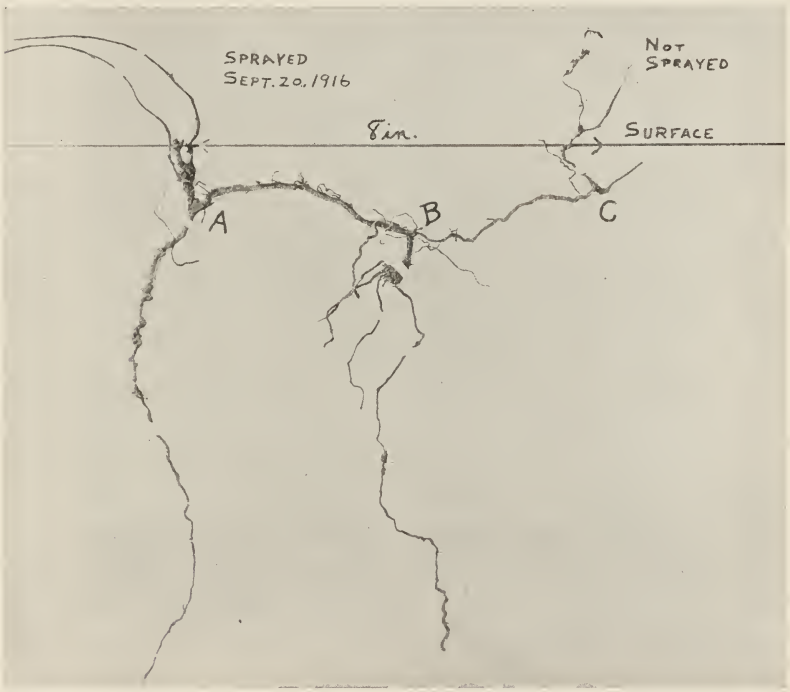


Fig. 11.—Typical morning-glory root system from the experimental plots on the campus at Berkeley.

The entire plant was in a state of disintegration when dug three weeks after spraying. The aerial parts originating from A were sprayed, while those originating from C were not sprayed. The vines originating from C were just beginning to wilt three weeks after the application of the spray above A.

as known, the general climatic conditions and local weather conditions at the time of spraying were practically the same at this point and on the plot on which the roots were entirely destroyed. Sprays were applied to mature vines at Berkeley many times during September and October, 1916, and in every case destroyed all signs of life in both vines and roots. Identical treatments in October at Centerville, at Spreckels, and in Ventura County resulted in very serious injury to the roots of the weed.

Another experiment which will throw light on the same matter was made at Davis. Two plots were selected, on one of which the plants were in full bloom and on the other in the green seed-pod stage. Identical sprays were applied to the two plots on the same day. Subsequent observations failed to reveal any injury upon the roots of the plants which were in full bloom at the time of spraying. The roots on the plot which was in the green seed-pod stage were seriously injured by the spray and fully 75 per cent of the roots failed to produce new sprouts within a month after the time of spraying. One root dissected out from this plot to a depth of three feet was found to be moldy and disintegrated throughout its entire length.

It thus appears that the most significant difference which may account for apparent conflicts of results was the difference in the stage of maturity of the plants. The remarkable phenomenon observed on the effect on the root systems of wild morning-glory vines produced by a late summer or fall spraying strongly suggests that the appearance of this phenomenon is intimately associated with the rest period of the plant. The increased downward flow of the sap of plants at the beginning of the rest period is well known to plant physiologists and appears to be a most significant fact in this connection.

*Influence of the Weather.*—Monthly climatological data for California have been received through the courtesy of the Weather Bureau of the United States Department of Agriculture. The reports from the weather station nearest the various experimental plots may be taken as indicating the approximate state of the weather at or near the time of treatment. In many cases the data were not sufficiently local or complete to determine accurately to what extent the results of the experiments were influenced by the weather. From a general survey of the weather data and the known facts concerning the influence of weather on foliage injury caused by insecticides and fungicides,[14] it seems evident that the most important weather condition influencing the results of the leaf-absorption method is the amount of moisture present at or near the time of treatment. The encouraging results obtained by the leaf-absorption method experiments in all the humid coast climates and the unsatisfactory results obtained by the same method in the semiarid climate at Davis strongly indicated that one essential condition of the successsful application of arsenic as an herbicide by the leaf-absorption method is the presence of sufficient moisture to prevent the drying of the poison on the leaves before its absorption.

Although none of the experiments at Davis was wholly satisfactory, even though applied to mature vines which had already ripened seeds, two sprays were made in the fall which quite seriously affected the roots of the morning-glory vines. In both cases, the root injury occurred from the sprayings which were immediately followed by damp weather.

*Possibilities and Limitations of the Method.*—The method described can not as yet be said to be one of eradication. It has been demonstrated, however, that 85 to 90 per cent of the morning-glory roots on the plots near the coast can be killed to a depth of four feet or more by a properly timed spray to mature vines. New sprouts will emerge from the stubs of the partially killed roots and will eventually reach the surface and produce new vines. Under these conditions they are, however, very puny, the leaves being only about one-fourth of the normal size and of a sickly yellowish color. The new growth is quite different from the normal trailing vine. When the new shoot reaches the surface, a thick clump of erect branches is produced not more than eight or nine inches in length. The majority of the new shoots consume from seven months to one year in reaching the surface so that a crop can be well established on the land, or an early crop harvested, without serious interference from the weed.

The abnormal condition of the vines originating from the stubs of the partially destroyed roots and the enfeebled condition of these root stubs lead one to believe that an annual fall spraying may eventually eradicate the weed.

## SUMMARY

None of the root-absorption experiments seemed to point the way for the control of wild morning-glory on agricultural land at a reasonable expense and without serious injury to the soil.

Incidental to the main object of the experiments, the control of wild morning-glory on agricultural land, data have been obtained which show the superiority of arsenic as a soil sterilizer. All of the Centerville plots to which an ounce or more of arsenic trioxide had been applied per square yard were barren of all vegetation, except wild morning-glory, for fourteen months notwithstanding the leaching by the rains of two winters.

The leaf-absorption experiments have definitely established one fact of importance from a scientific as well as from a practical stand-

point, namely, that a dilute solution of sodium arsenite applied only to the aerial parts of the wild morning-glory under certain conditions will destroy both the aerial parts of the plant and the underground parts to a depth of several feet.

The experiments point strongly toward the conclusion that the accomplishment of these results is chiefly dependent on the coexistence of two conditions at the time of the application of the poison, namely that:

1. The plant is approaching or wholly within the dormant state.
2. Sufficient moisture is present in the air to prevent the drying of the poison on the leaves before its absorption.

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